Very Low Flux Infrared Detectors for Planet Finder Requirements

Presented to:

NGST Annual Technology Challenge Review #1

NASA/Goddard Space Flight Center

July 7-10, 1997

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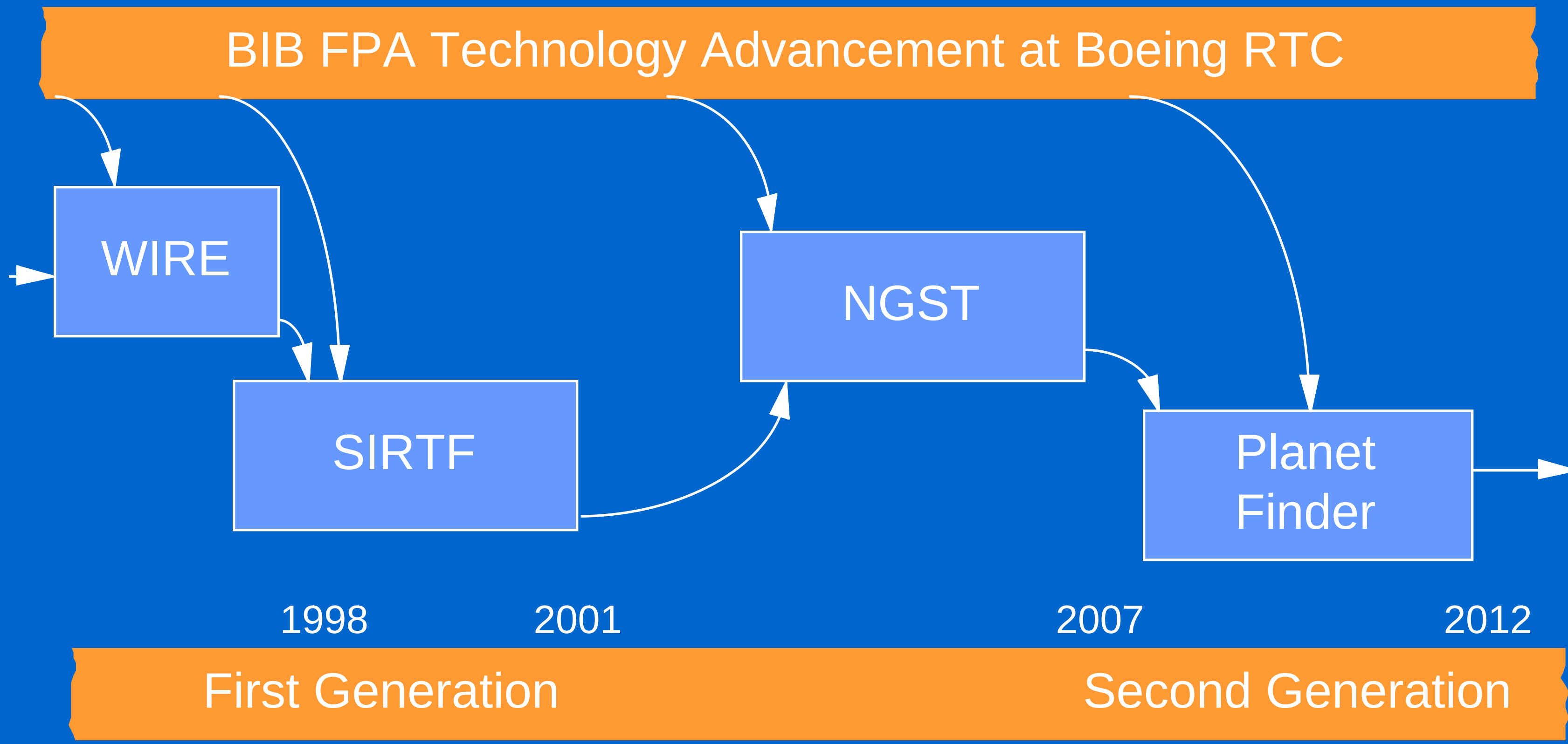
Sponsored by NASA/Jet Propulsion Laboratory under Contract NAS7-918

Introduction

- **Detector Needs for Planet Finder (PF) and NGST**
  - Dark Current and Read Noise Reduction
  - Companion presentation “Boeing Mid-IR BIB FPA Technology”
- **Blocked Impurity Band (BIB) Technology Overview**
- **PF Detector Development Task at Boeing RTC**
  - Approaches
  - Progress

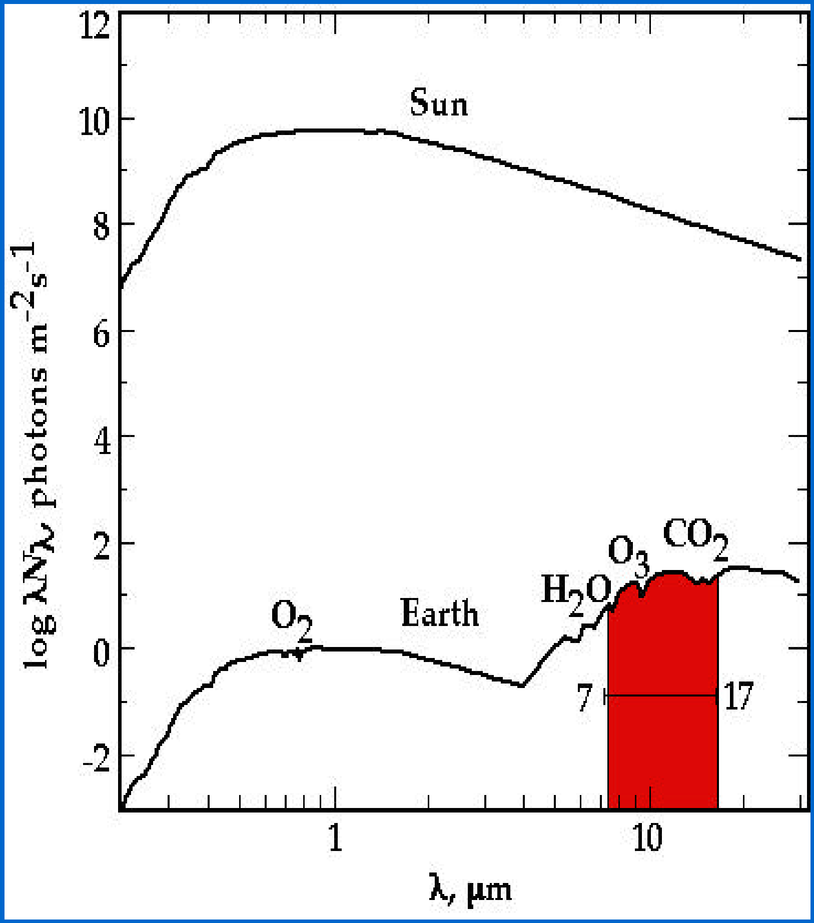
Space-Based Origins Missions for Mid-IR BIB FPA’s



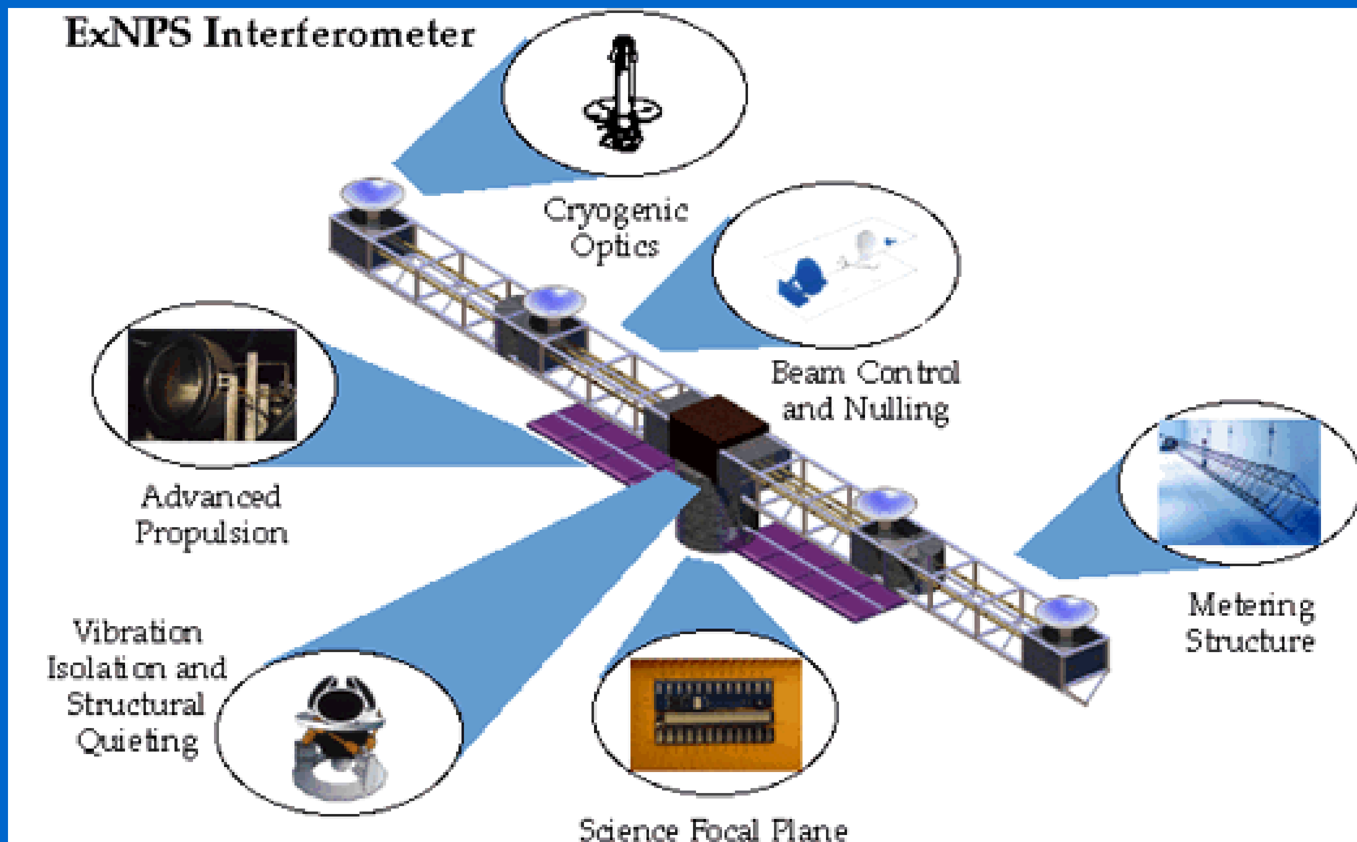
NGST can benefit from detector development already being directed toward Planet Finder requirements

Planet Finder Mission

- Direct detection of habitable planets from space
- IR photometry for size and temperature
- Orbits by direct imaging
- Planet spectra in 7 µm to 17 µm band
  - water 7 µm habitability
  - ozone 9.5 µm photochemistry photosynthesis?
  - CO_2 15 µm atmosphere



IR Focal Plane is a Core PF Technology



Planet Finder Detector Needs

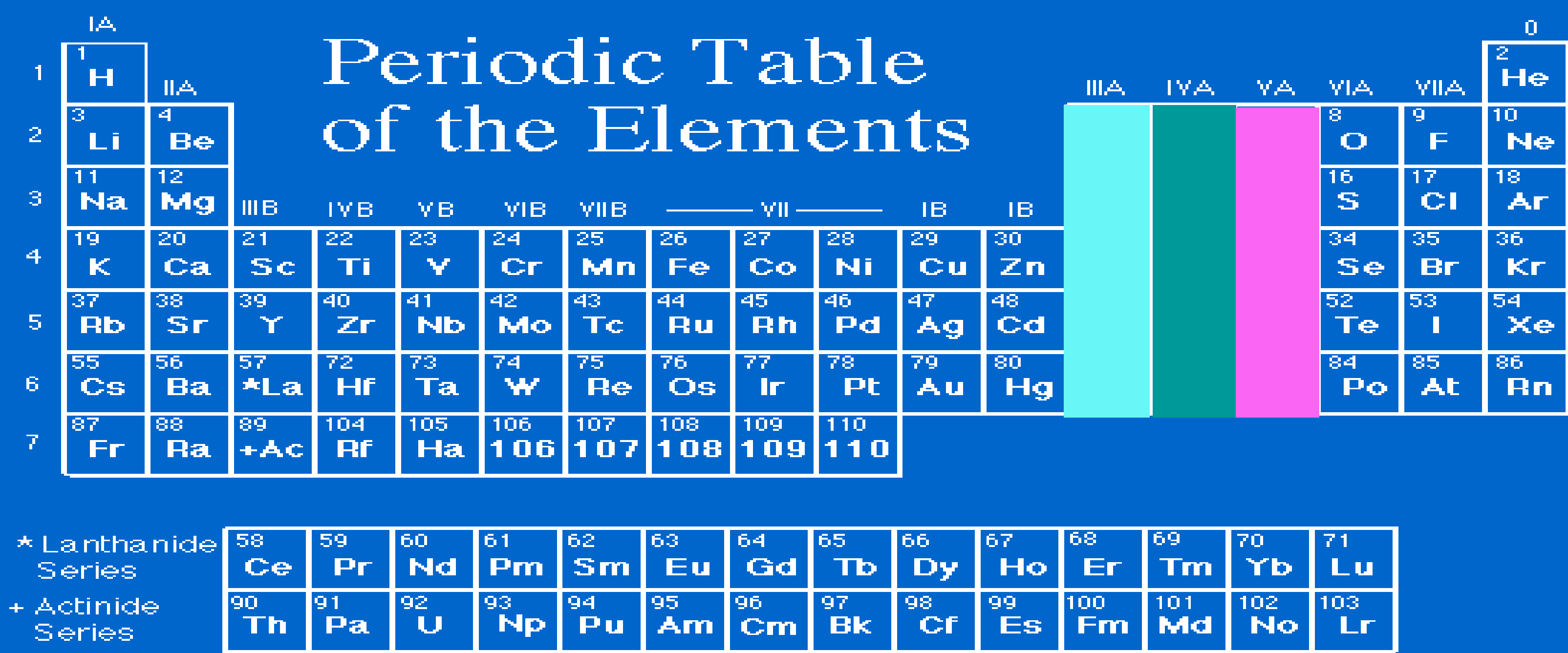
Parameter		NGST
Array size	~10x50	512x512
Pixel size	~(100 μm)^2	~(27 μm)^2
Dark current	< 2 e/s (goal < 1 e/s)	goal < 1 e/s
Read noise	< 8 e (goal <1 e)	goal < 15 e/read
Background	600 ph/m^2/s (at aperture)	
Signal level	2.3 ph/m^2/s (at aperture)	
Temperature	5-10 K (highest possible)	
Integration time	TBD (> 10 s)	

Low sensitivity to ionizing radiation damage

PF Dark current and read noise more stringent than NGST
BIB FPA development should benefit NGST

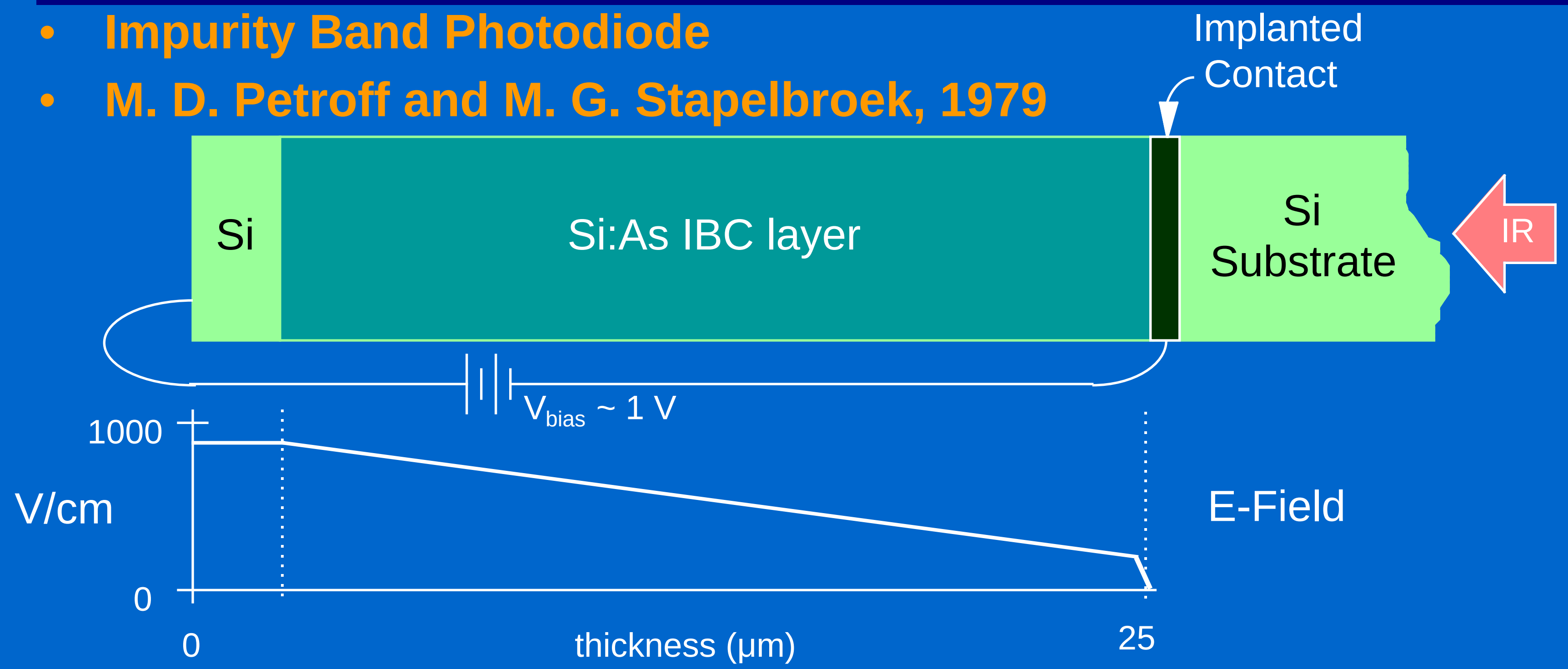
Impurity Band Conduction (IBC) Material

- Single-crystal Group IV semiconductor
- Heavily doped with Group V (donors) or Group III (acceptors)
- Si:As, Si:Sb, Si:Ga, Si:P, Ge:Ga, Ge:B
- Below carrier freeze-out, conduction through impurity states



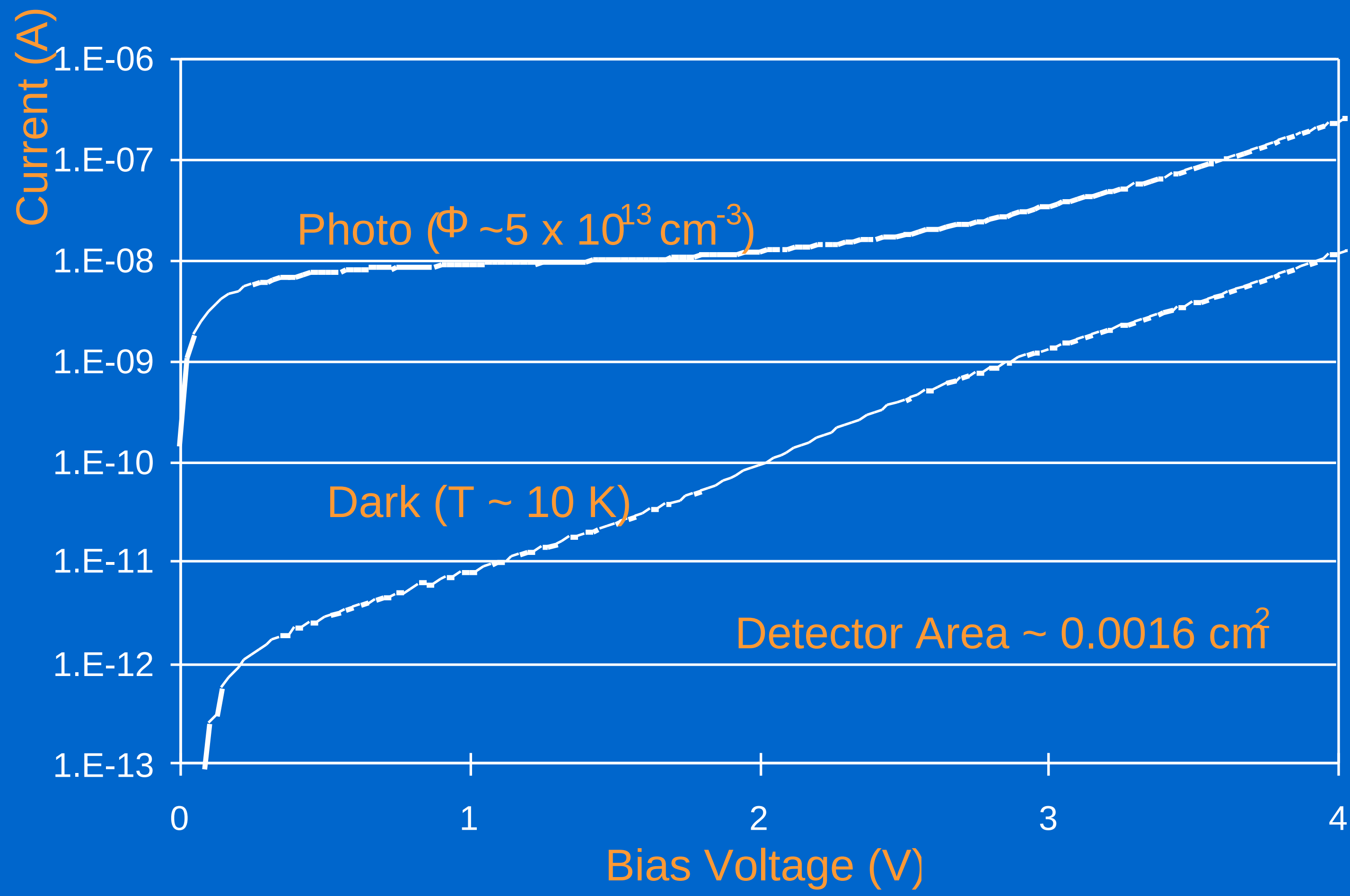
Si:As Blocked Impurity Band Detector

- **Impurity Band Photodiode**
- **M. D. Petroff and M. G. Stapelbroek, 1979**



- **Impurity band conduction blocked by undoped silicon layer**
- **Generated carriers swept out and detected:**
  - Optical up to λ~28 μm for Si:As (photoresponse)
  - Thermal ~ exp($-E_{act}/kT$), E_{act}~22 meV (dark current)

BIB Detector Currents



BIB Detector Model

- **One-dimensional finite-element model**
- **Inputs:**
  - BIB layer structure with donor and acceptor profiles
  - Operating conditions
- **Outputs:**
  - Infrared transmission, absorption, reflection
  - Electric field profile for given bias
  - Optical and thermal generation for given operating temperature
  - Impact ionization multiplication and approximate noise contribution
  - Other phenomena
- **Implemented as a spreadsheet calculation**

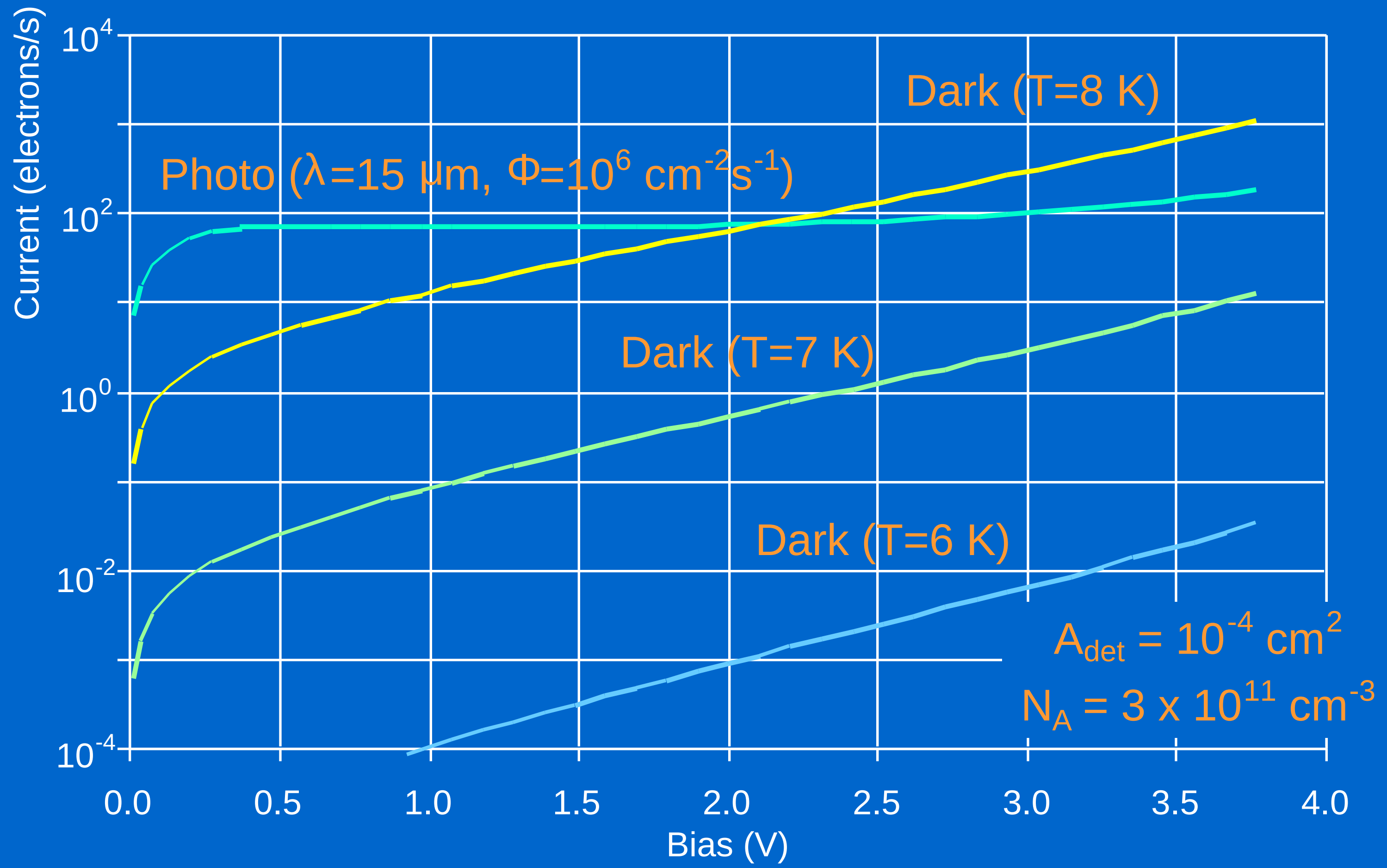
Planet Finder Task at Boeing RTC

- **"BIB Detector Technology Development" contract (also includes Ge BIB detector development)**
- **Customer: NASA Jet Propulsion Laboratory**
  Dr. Virendra Sarohia
- **Task Start: 6/13/96**
- **Objective: Demonstrate FPA's for PF requirements**
- **Approach: Extend current BIB FPA technology**
  - Vary Si:As BIB layer design. Evaluate Si:Ga
  - Tailor circuit designs and/or cryo Si readouts

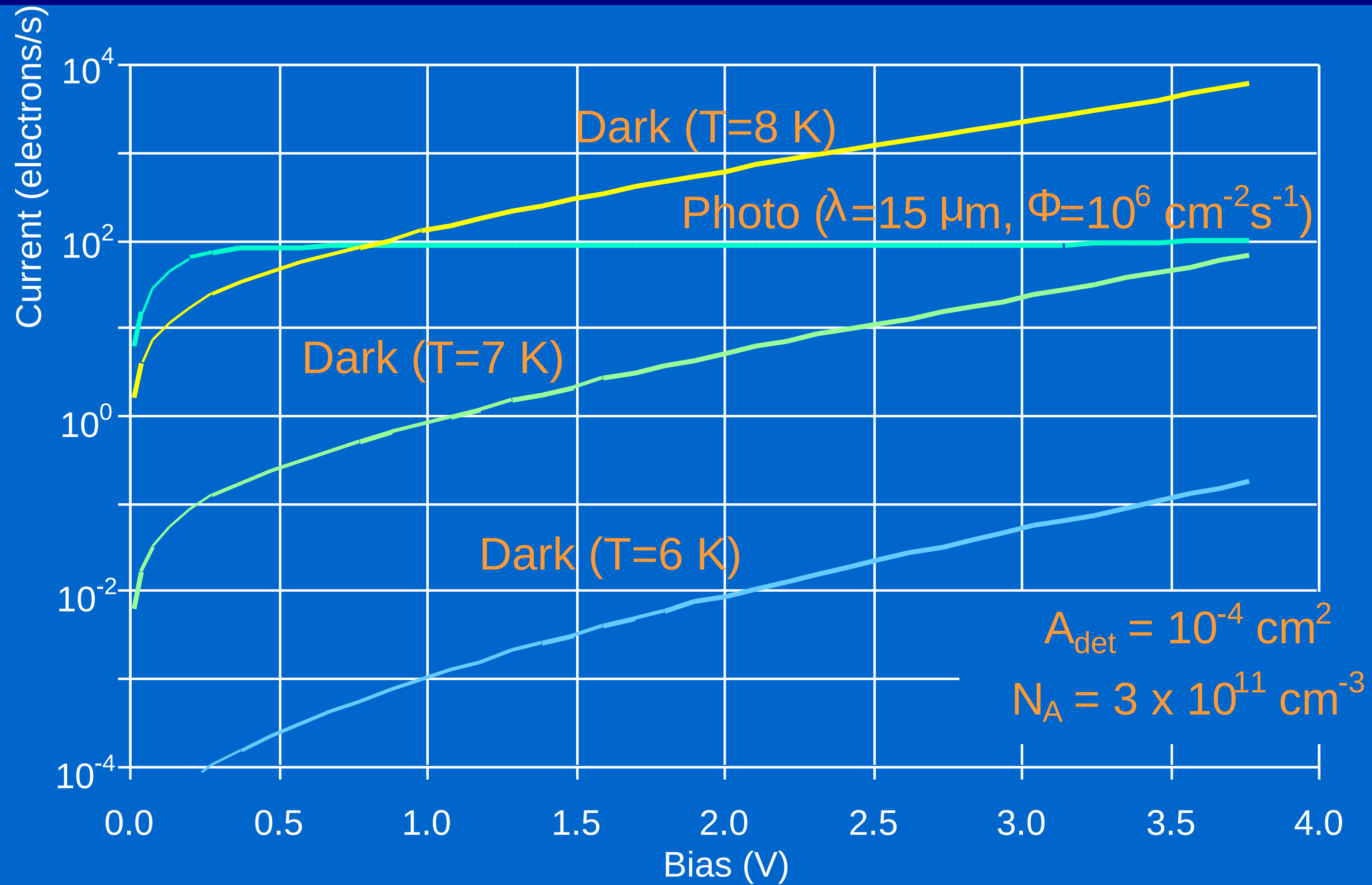
Dark Current Reduction

- **Modify Si:As material design**
  - Reduce donor concentration (N_D) from nominal 8×10^{17} cm^{-3}
  - Increase blocking layer (BL) thickness from nominal 3 μm
  - Use growth methods for lowest available acceptor background N_A
- **Evaluate Si:Ga**
  - Lower $\lambda_{cut\text{-}off}$ (OK for PF), operates warmer for given I_{dark}
  - Material quality and detector process not yet demonstrated
- **Progress**
  - Characterization data taken from WIRE/SIRTF, other devices
  - Parameters for improved new material defined using BIB model
  - New material grown at LSRL - near design targets
  - Device fabrication begun
  - LSRL to provide Si:Ga material for evaluation on this project

Calculations for PF Epitaxy Split A

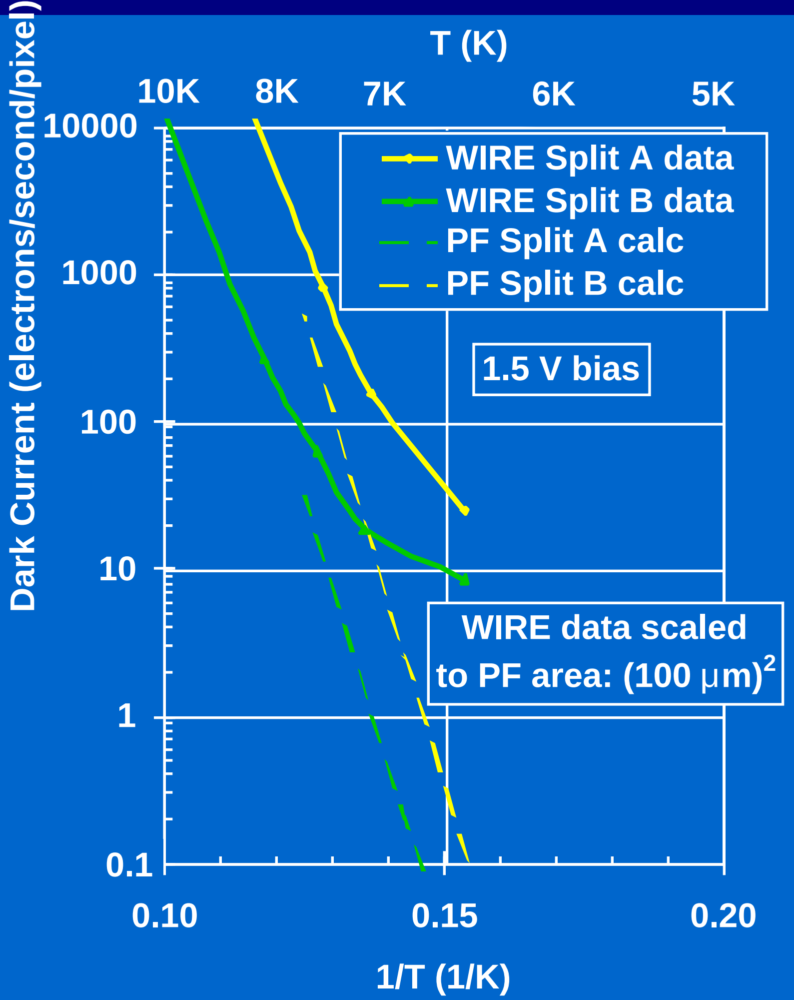


Calculations for PF Epitaxy Split B



Expected Dark Current Improvement

- **Lower donor doping effect**
  – Reduced dark current vs temp
  – Modest improvement over WIRE
  – Projected 1-e level is above 7 K
- **Thicker blocking layers effect**
  – Expect reduced leakage
  – Achieve 1-e/s level
  – WIRE leakage ~10 e/s
- **Reduced acceptor background**
  – Should allow lower-bias operation
  – Still good radiometric performance



Read Noise Reduction

- **Analyze feasibility of extending present cryogenic silicon BIB FPA readout designs/technologies**
  - Bulk CMOS
  - Silicon on Insulator
  - Including in-cell gain
  - Power consumption issues
  - Alternate technologies: Ge JFET
- **Progress**
  - Passive input cells extensions considered, ~8 e achievable only if multiple sampling allowed
  - Active in-cell components will be needed for 1-e goal

Conclusion and Plans

- Spin-off from NASA/JPL Planet Finder detector development at Boeing RTC should benefit NGST Mid-IR detector development
  - Comparable detector dark current requirements
  - Overlap in readout development too, but needs are different
    - NGST: large arrays, read noise <15 e/read, passive circuits possible
    - PF: goal <1 e, active circuits required; OK for small arrays
- First detectors directed toward PF requirements now in processing
- Test results will guide design of improved detectors for fab next year
- PF readout requirements being studied
- Readout design in next program phase, to begin later this year
- First readouts and FPA's next year
- Will seek demonstration vehicles